Comparison of Thermal Shock Damages Induced by Different Simulation Methods on Tungsten

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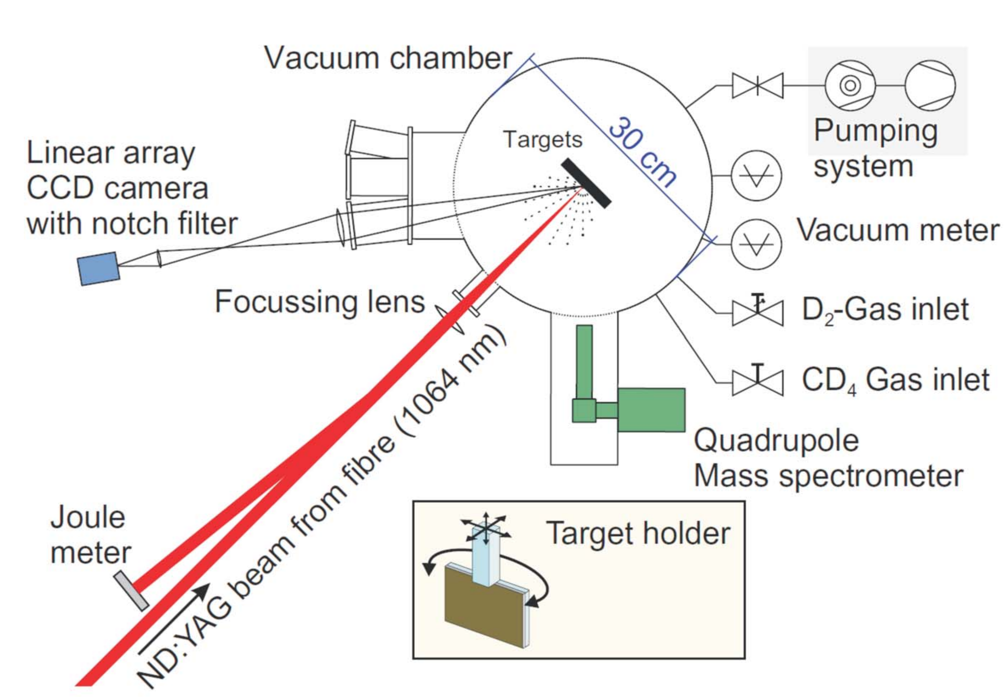
Introduction

Motivation: Comparison of laser and electron beam methods to simulate ITER relevant ELM-like thermal shock events to quantify potential differences in the thermal shock response of the PFM tungsten.

Nd:YAG laser

layout data:

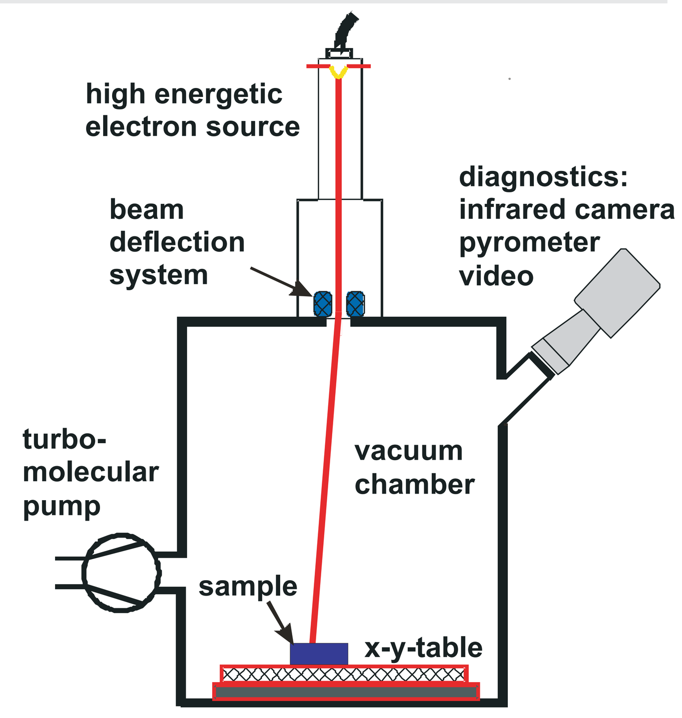
- λ = 1064 nm
- laser beam Ø = 6 mm
- fibre-optics core Ø = 400 µm
- pulse duration: 0.1 - 20 ms
- repetition rate: 0.1 - 100 Hz
- max. beam power: 20 kW
- max. beam energy: 60 J
- position accuracy: < 0.5 mm



Electron beam facility JUDITH 1

layout data:

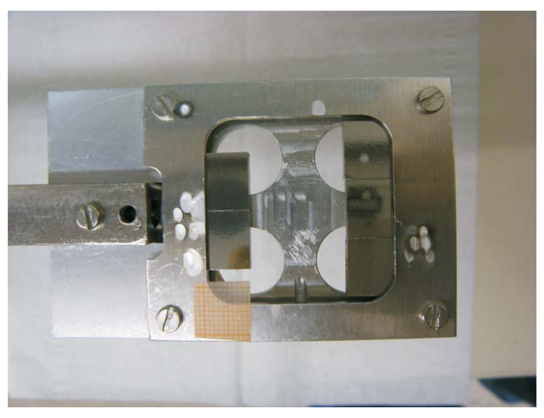
- max. power: 60 kW
- acceleration voltage: ≤ 150 kV
- electron current: ≤ 400 mA
- max. loaded area: 100 x 100 mm^2
- scanning frequency: ≤ 100 kHz
- pulse duration: 1 ms ... continuous
- beam diameter: 1 mm (FWHM)



Experiments & Results

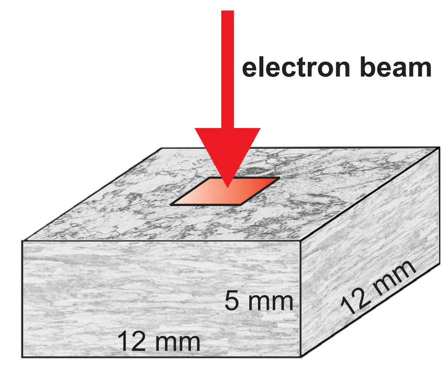
Experimental settings Nd:YAG laser

sample size:	12 × 12 × 5 mm^3
loaded area:	Ø = 2 mm
base temperature:	RT
power density:	0.19 up to 1.51 GW/m^2

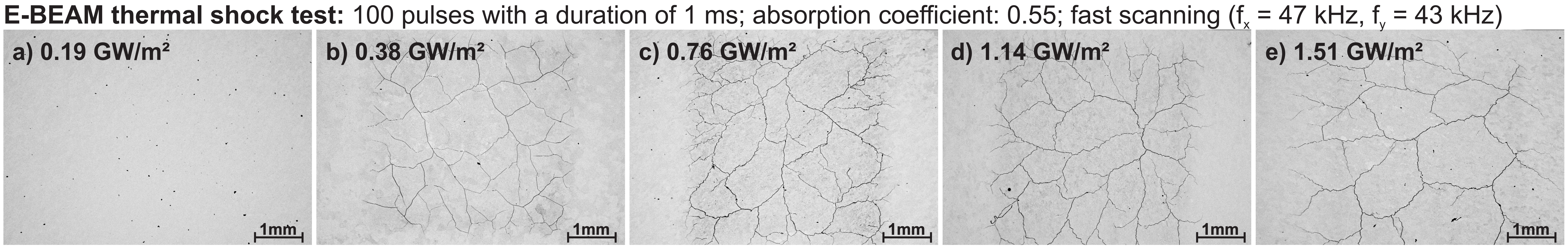


Experimental settings JUDITH 1

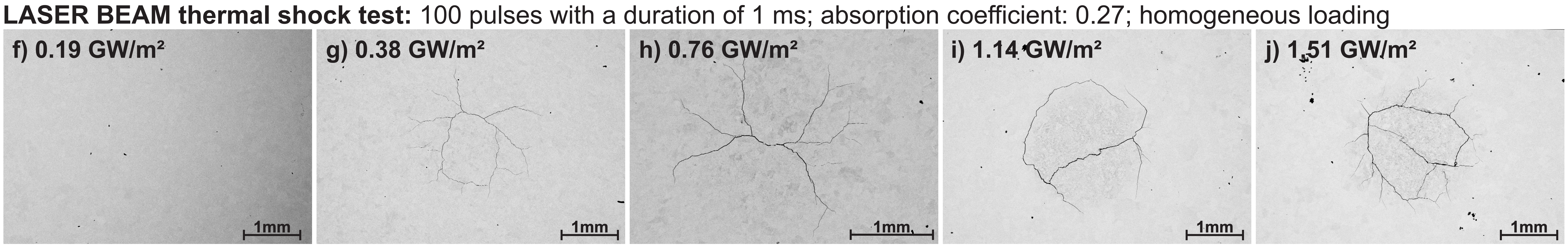
sample size:	12 × 12 × 5 mm^3
loaded area:	4 × 4 mm²
base temperature:	RT
power density:	0.19 up to 1.51 GW/m^2



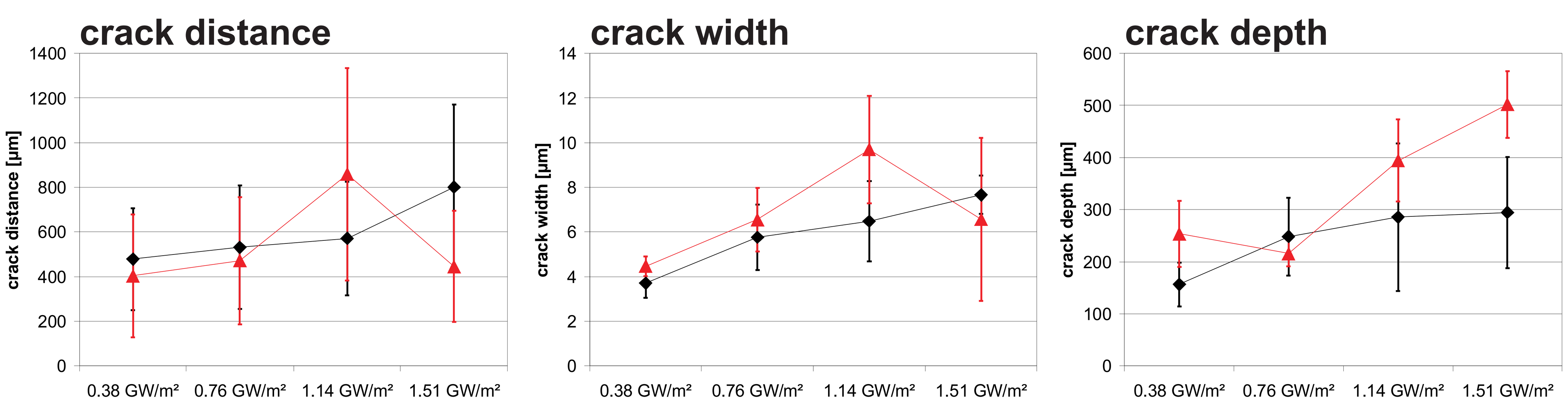
E-BEAM thermal shock test: 100 pulses with a duration of 1 ms; absorption coefficient: 0.55; fast scanning (f_x = 47 kHz, f_y = 43 kHz)



LASER BEAM thermal shock test: 100 pulses with a duration of 1 ms; absorption coefficient: 0.27; homogeneous loading

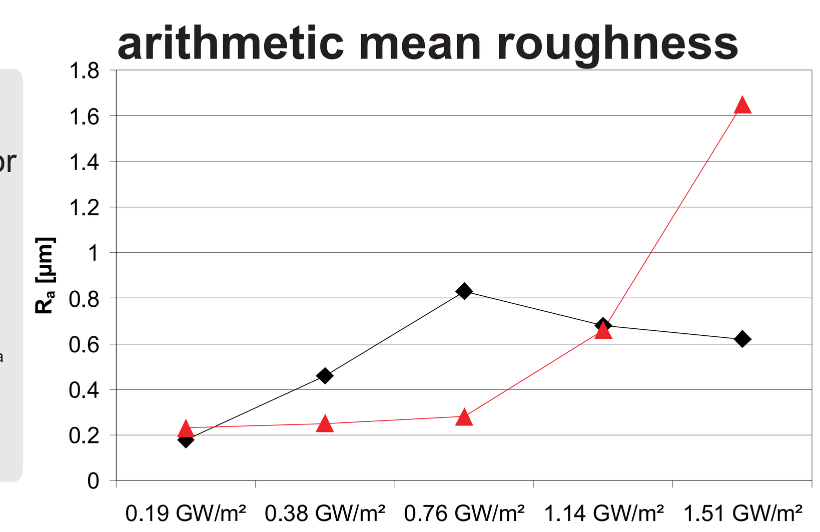


Investigation of crack networks



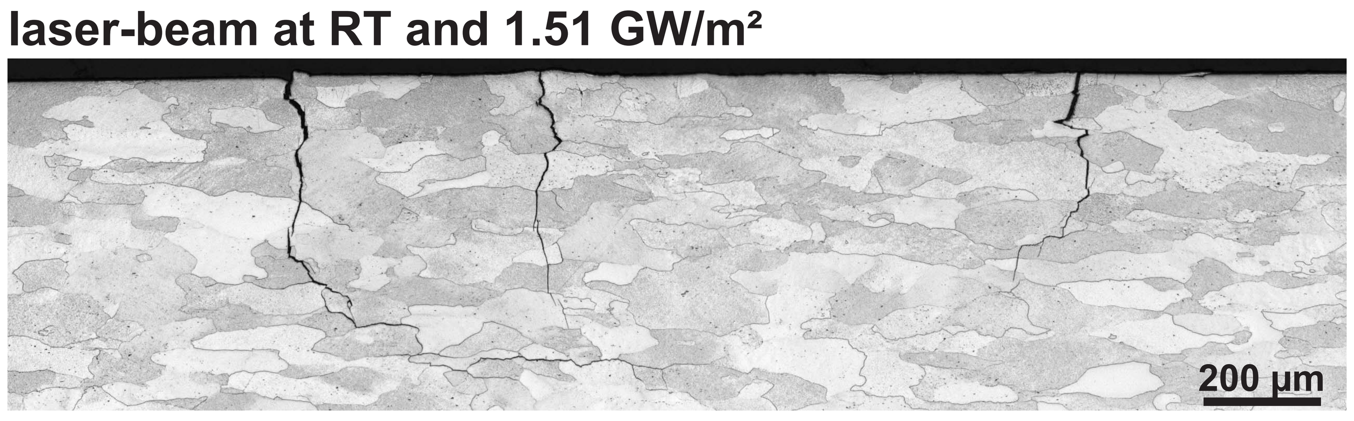
- increase of crack distance, width and depth
- similar parameter values for both simulation methods
- problems to achieve statistically firm data
- e-beam: fast increase of R_a to a constant value
- laser: slow but constant increase of R_a

Roughening



Crack propagation into the bulk material

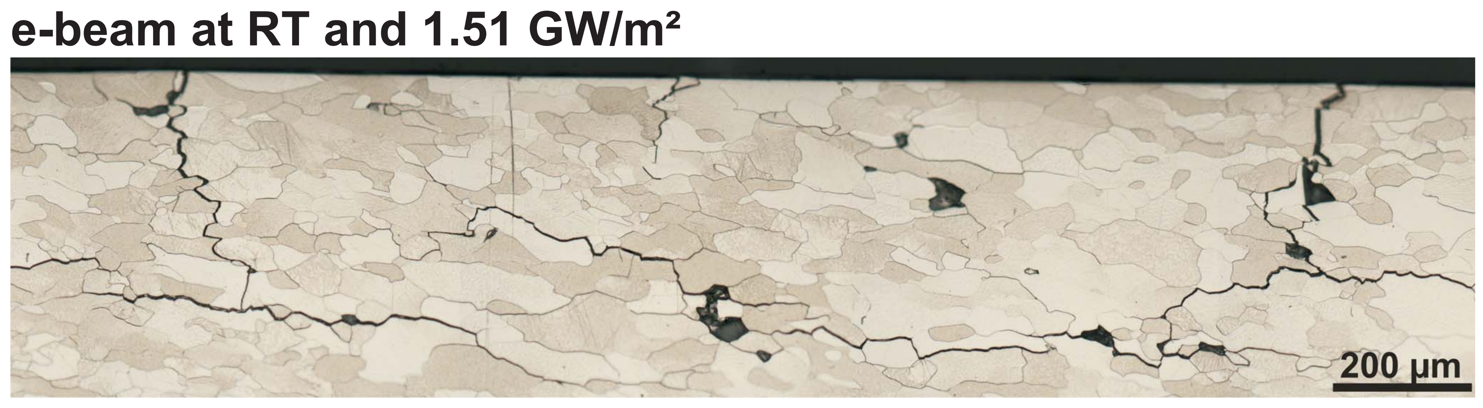
laser-beam at RT and 1.51 GW/m²



Similar crack propagation for both simulation methods. Cracks grow perpendicular to the loaded surface, stop at a certain depth (150 - 600 µm) and propagate parallel to the surface.

→ danger of surface erosion

e-beam at RT and 1.51 GW/m²



Conclusion

- volumetric loading in case of the electron beam (penetration depth in W in the µm range); surface loading with the laser beam (22 nm light decay length)
- different simulation methods have no qualitative influence on thermal shock damage behaviour and pattern of tungsten (damage threshold between 0.19 GW/m² and 0.38 GW/m² at RT, valid for 100 pulses)
- thermal shock crack formation and parameters like distance, width and depth are very similar and show only slight differences due to geometric differences of the exposed areas
- differences in the arithmetic mean roughness (R_a) are related to geometric differences but also to high frequency scanning with the e-beam in contrast to steady and homogeneous loading by the laser

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